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Active MRI Tracking For Robotic Assisted FUS

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Abstract: MR guided FUS is a noninvasive method producing thermal necrosis at the position of tumors with high accuracy and temperature control. Because the typical size of the ultrasound focus is smaller than the area of interested treatment tissues, focus repositioning become necessary to achieve multiple sonications to cover the whole targeted area. Using MR compatible mechanical actuators could help the ultrasound beam to reach a wider treatment range than using electrical beam steering technique and more flexibility in position the transducer. An active MR tracking technique was combined into the MRgFUS system to help locating the position of the mechanical actuator and the FUS transducer. For this study, a precise agar reference model was designed and fabricated to test the performance of the active tracking technique when it was used on the MR-compatible robotics InnoMotion™ (IBSMM, Engineering spol. s r.o. / Ltd, Czech Republic). The precision, tracking range and positioning speed of the combined robotic FUS system were evaluated in this study. Compared to the existing MR guided HIFU systems, the combined robotic system with active tracking techniques provides a potential that allows the FUS treatment to operate in a larger spatial range and with a faster speed, which is one of the main challenges for organ motion tracking.

I. INTRODUCTION

Focused ultrasound surgery (FUS) has been proved to be a precise and non-invasive modality for tissue ablation in experimental and clinical studies. Focus precision and energy efficiency of the FUS therapy highly benefit from guidance and monitoring by magnetic resonance (MR) imaging[1].

As the typical spatial volumes of the ultrasound focus are smaller than the target volume, a complete HIFU intervention requires multiple sonications and focus repositioning[2]. Such focal spot scanning techniques can be realized via mechanical actuators. We propose an MRgFUS system that combines an US transducer with a fixed focal length and a robotic assistance system to steer the US beam. The MRI active tracking technique is integrated with the robotic FUS system and the MRI to enable fast systems localization.

This combined approach would provide a wide range of spatial flexibility for positioning of the high power ultrasound transducer within the magnet bore. The combined robotic arm assisted FUS setup might offer additional acoustic treatment pathways which could, for example, avoid bone structures during sonication without taking the patients off from the scanner. In our previous work[3], an active tracking technique was applied on the robotic arm to precisely detect the position of the system. The tracking accuracy was tested without considering the system error caused by the robotic arm itself. Here in this paper, a new agar phantom structure is designed to be as the external reference model. Furthermore, a MRI compatible web camera is fixed in the MRI suite to monitor the relative

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position relationship between the robotic arm and the reference model to make sure the robot arm could move to the right position. A higher tracking accuracy result has been achieved with technique described in this paper.

II. METHODS

The Mechanical device used for moving US transducer is a MRI-compatible robotic arm (IBSMM Engineering spol. S r.o./Ltd., Czech Republic) (FIGURE. 1a). This robotic system is driven pneumatically in 5 degrees of freedom with a translational and an angular positioning accuracy of ±1 mm and ±1°, respectively4.

During the motion of the robotic arm, a way of detecting the coordinates of the robot within the MR core, which is named active tracking is used in this work. The tracking technique is based on a fundamental principle of MR imaging that the magnetic field5. To realize the tracking, a tracking plate made of PVA (FIGURE 1b) is designed on which there are 4 trackers, each of them contains a volume of fluid in a dedicated coil provided by InSightec Ltd. (Tirat Carmel, Israel). The size of every coil is about 2mm in diameter and 5mm in length. This device allows mechanical connection between the robotic arm and the FUS transducer.

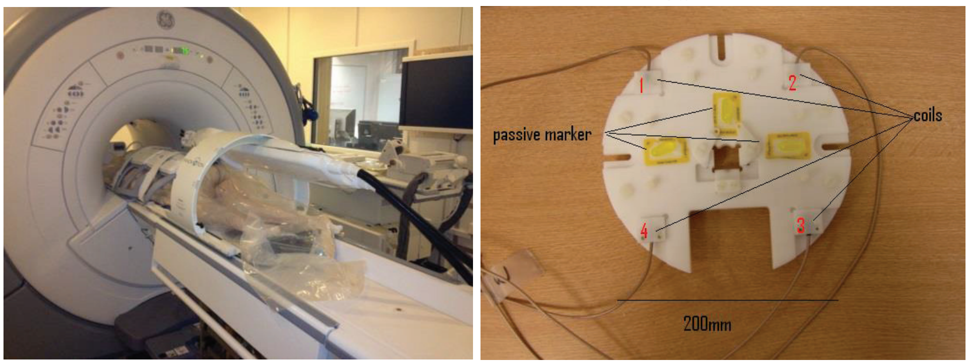

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FIGURE 1.(a) View of an Innomotion robotic arm guided MR intervention (GE 1.5 Tesla HDx) (b) MR tracking device with 4 active micro coils (Insightec)

To prove the efficiency of active tracking method, a calibration experiment is built up which can test the tracking accuracy when using micro-coils to get the positions of the robotic arm. To this end, a 3D reference model is designed to provide reference points for the robotic arm.

These reference points are precisely located on the reference frame (FIGURE 2a) which is made of 5% proportion agar. The model is 140*140*140mm in dimension which is much larger than normal beam steering space of phased array transducers. If the robotic arm can precisely locate a HIFU transducer in this wide space volume, a conclusion can made that the mechanical guiding method is worth for HIFU applications in which the ultrasound beam has to steer in a wide range or the beam has to be adjusted to avoid interference rib bone. The 35 reference holes are located uniformly on seven different layers, the height distance between two adjacent layers is 20mm and the lateral distance between two adjacent holes is 30mm.

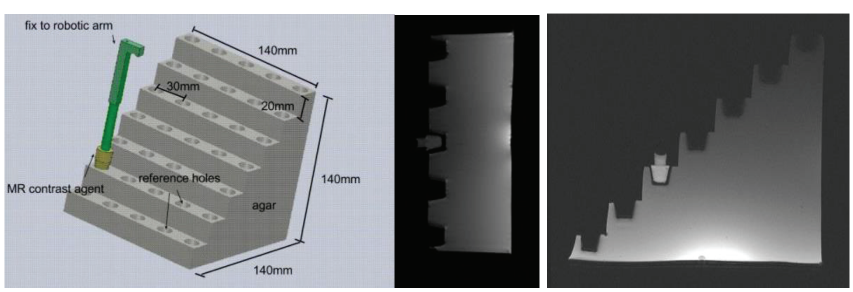

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FIGURE 2. (a)Agar phantom for providing reference points; (b)Sagittal and axial MR scan (imaging data) of agar phantom and Gd (1 Gd:100 water) filled head of application part

In the calibration experiment, a needle shaped application part (FIGURE. 2) was fixed at the center of the tracking device. The head of the application part was filled with Gadolinium (Gd) with a ratio to gelatin of 1:50. This application part will appear brighter than the agar phantom, which can help the observer to confirm the position of the robotic arm (FIGURE 2b).

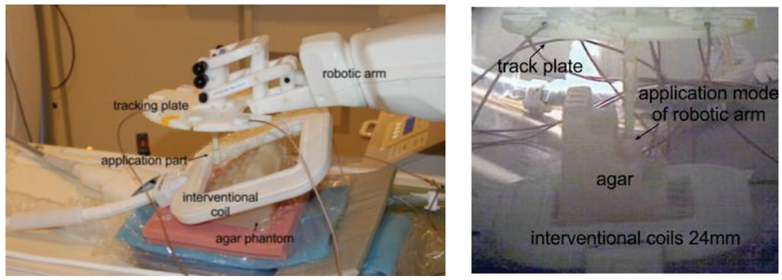

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FIGURE 3. (a)Robotic arm guides the application part inserting into the reference holes of the agar phantom; (b) Using external camera to monitor the position of the robotic arm in the MR scanner (GE 1.5 Tesla HDx, DuoFlex Interventional coil by MRInstruments)

The robotic arm guides the needle to align with the reference points of the phantom (FIGURE. 3). At every reference position, the robotic arm position could be computed from the coordinate readout of the four micro coils. Comparing the computed coordinates with the reference coordinates, the tracking reliability of the micro coils methods could be tested.

III. RESULTS

The whole tracking area is defined as the robotic arm movement range which is 180 mm in axial direction, 160mm in sagittal direction and 180mm in coronal direction. The coordinates of the micro coils in the MRI frame are recorded in less than 0.02 second. The computed in plane center of the four micro coils represents the position of the robotic arm. By comparing the position with the reference data, the tracking accuracy results have been calculated.

Table 1 is the summary of the tracking error in the whole range. In the more homogeneous magnetic area, the tracking error is smaller than 0.41mm, almost one third of the error in the area far from the iso-centre of the MR scanner. The error (in the coronal direction is larger than in the other two directions, which might come from two reasons. Firstly, it is more difficult to ensure the application part to touch the bottom of the reference holes of the phantom. Second, during the long period of tracking experiment, the agar and water based phantom shrinks most in the coronal direction because of its self-weight.

TABLE 1 Summary of the tracking result in the area close to the iso-centre of the MR

Direction & Distance to isocenter	Error (mm)	Direction & Distance to isocenter	Error (mm)
Axial, <120mm	30.03±0.28	Axial, ≥120, ≤180mm	30.03±0.60
Sagittal, <120mm	20.04±0.28	Sagittal, ≥120, ≤160mm	20.04±0.66
Coronal, <140mm	19.76±0.41	Coronal, ≥120, ≤180mm	19.60±1.30

IV. DISCUSSION AND CONCLUSION

After replace the needle shaped application part with a HIFU transducer, the system supposed to be able to guide the transducer to steer the US beam in a wide range. The combination of a commercial robotic arm and a customized active tracking device was proposed as a new type of experimental setup for validation of future MRgFUS therapy. The newly designed agar phantom modal provide more reliable calibration result for the tracking technique.

Compared to existing MR guided HIFU systems, the combined robotic HIFU with the active tracking technique facilitates the HIFU treatment to operate in a larger spatial range (at least 14×14×14 cm) and at faster speed. This MR compatible active tracking device should provide a significant reduction the treatment time as it obviates the need for time consuming manual repositioning.

V. ACKNOWLEDGEMENT

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